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UNCLASSIFIED

DIRECTORATE OF WEAPON RESEARCH (DEFENCE)

Investigation of the Corrosion Resistance of B.S. Aluminium Alloys H. 10 and H. 15

Review of Progress 1953

by

Winifred A. Bell, B.A.

and

E.A.G. Liddiard, M.A., F.I.M.

Work carried out in connection with Ministry of Supply E.M.R. Contract 6/GEN/1144 at Fulmer Research Institute Ltd

DECEMBER, 1953

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Foreword

This report describes further work on the Corrosion of Aluminium Alloys H.10 and H.15 carried out by the Fulmer Research Institute under an extra-mural contract for the Ministry of Supply.

The following reports on this investigation have already been issued:-

WR(D) Report 7/51 - "Investigation of the Corrosion Resistance of A.W.10 and A.W.15." 4th Report - October, 1950.

WR(D) Report 14/51- "Investigation of the Corrosion Resistance of A.W.10 and A.W.15". November, 1951.

WR(D) Report 7/52 - "Investigation of the Corrosion Resistance of A.W.10 and A.W.15 - Report on Laboratory Work." August, 1952.

WR(D) Report 7/53 - "The influence of Extrusion Direction on Corrosion and Stress Corrosion Behaviour of H.E.15 W.P. Aluminium - Copper - Magnesium Alloy." July, 1953.

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for Director of Weapon Research (Defence)

Room 854 Shell Mex House.
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December, 1953.

K. 172811

FULMER RESEARCH INSTITUTE LIMITED

R.22/9/November 1953.

INVESTIGATION OF THE CORROSION RESISTANCE OF H.10 (Al/0.7% Mg/1.0% Si) AND H.15 (Al/4% Cu/0.1% Mg) ALUMINIUM ALLOYS.

REVIEW OF PROGRESS 1953.

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CORRIGENDUM

P. 16. Last line.

P. 17. Lines 4, 13 and 15.

Insert the word "solution before "heat treatment" in each case.

P. 17. Line 9.

Insert the word "solution" before "heat treated".

K.179539

CONTENTS

FULMER RESEARCH INSTITUTE LIMITED

R.22/9/November 1953.

INVESTIGATION OF THE CORROSION RESISTANCE OF H.10 (Al/0.7% Mg/1.0% Si) AND H.15 (Al/4% Cu/0.1% Mg) ALUMINIUM ALLOYS.

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1. INTRODUCTION.

The work described in this report is a continuation of the work described in R.22/5/November 1951, (Field Tests), R.22/6/July 1952, (Laboratory Tests), and R.22/7/August 1952, and R.22/8/June 1953 (Stress Corrosion Tests), and covers the work from the time these reports were written. During this period the investigation has been extended to study the effect of welding on the corrosion of H.10 and H.15, to study the prevention of stress corrosion on HS.15 by painting, and to determine a safe level of stress below which stress corrosion will not occur in H.15 sheet and extrusions when stressed transverse to the extrusion direction.

The main part of the investigation has, however, been a continuation of work which had already been in progress and the greater part of this work has now been completed, with the exception of long term field tests of the original HE.10 and HE.15 channel sections, and HE.10 containing eight different amounts of copper.

This work has been carried out at the Fulmer Research Institute under the sponsorship of the Ministry of Supply.

2. MATERIAL USED.

The original materials used for this investigation were channel section extrusions made from normal batches of H.10 and H.15 billets. The extruded sections were $1\frac{1}{4}$" x 1" x 1" channel with a thickness of 0.1". They were made by the normal production methods. The HE.10 was die quenched and the HE.15 was quenched after solution heat treatment. The channels were then stretched to straighten, the amount of stretching being of the order of 3% although it may have varied between 1% and 8%. Lengths were cut as required and were given the appropriate ageing treatment.

Chemical analyses of the extrusions were as follows:-

HE.10 -	Cu	0.04% (max)	Mg	0.68%		
	Si	0.98%	Fe	0.27%		
	Mn	0.04%				
HE.15 -	Cu	3.81%	Si	0.95%	Fe	0.25%
	Mn	0.54%	Mg	0.74%	Ti	0.02%

The specifications covering these alloys are as follows:-

HE.10	BS.STA 7/AW.10; BS.1476, HE.10WP.
HE.15	BS.STA 7/AW.15; BS.1476, HE.15WP and DTD.364A.

The ageing temperatures used for the field tests and laboratory tests, unless otherwise stated, were 8 hours at 175°C. for HE.10, and 8 hours at 170°C. for HE.15. This material has been used for the long term field tests, and for the laboratory tests in effect of relative humidity and the simulation of out-door exposure tests. Specimens of HE.15 were used in the part of the work investigating the effect of removal of corrosion product.

In addition to the above material some similar extrusions were made from separate melts of HE.10 containing various amounts of copper. These alloys have only been used for a section of the investigation and the full details of the chemical composition will be given later as appropriate.

In order to determine the effect of manganese on the stress corrosion properties of H.15, tests have also been made on sheet and extruded material made from cast billets of H.15, one containing low manganese content 0.08% and the other a normal manganese content 0.76% Mn. The full details of fabrication and chemical composition are given in Appendix I, and are referred to in the appropriate section of the report.

The H.10 and H.15 material used for the welding experiments was supplied by M.E.X.E. Spectrographic analysis of the two materials is as follows:-

H.10	Plate.	Fe	.33	Si	1.14	Mg	.45	Cu & Mn< .04	
	Weld.	Fe	.28	Si	1.70	Mg	.29	Cu & Mn< .04	
H.15	Plate.	Fe	.45	Si	.72	Mg	.46	Mn .74	Cu 4
	Weld.	Fe	.39	Si	1.70	Mg	.33	Mn .65	Cu 4.

3. FIELD TESTS.

3.1. Long Term Exposure Field Tests on HE.15 and HE.10 Alloys.

(a) General.

The results of the first series of tests concerning exposure in field tests for up to 2 years failed to give a complete picture of the rate of corrosion damage on HE.10 and HE.15 alloys (R.22/5). It was decided to expose specimens from the original batch of material at the most severe sites and examine them after 1, 2, 4 and 8 years' exposure. The results of these repeat tests after one and two years' exposure have now been obtained. The sites chosen were as follows:-

<u>Site I</u>.	Sheffield - Brown Firth, Princess Street. B.I.S.R.A. exposure site.	Severe industrial.
<u>Site II</u>.	Roof of B.N.F.M.R.A. Euston Street, London.	Normal industrial.
<u>Site III</u>.	Hayling Island.	Marine atmosphere.
<u>Site V</u>.	Hayling Island.	Total immersion. (sea water)
<u>Site VII</u>.	Christchurch. M.E.X.E.	Total immersion. (fresh water)

Stressed and unstressed specimens were exposed as previously. The stresses used were the maximum design stress (5.1 T/in^2 for HE.10 and 16 T/in^2 for HE.15) and 0.1% proof stress (15 T/in^2 for HE.10 and 24 T/in^2 for HE.15). The method of stressing was by four point bending in a special frame so that the middle 7" of the specimens was at uniformly constant strain. The stresses in the specimens would, of course, tend to decrease during the tests as a result of creep and decrease in effective thickness of the specimens by corrosion.

Pieces of channel extrusion were bolted to the frames and one was removed along with three of specimens at each stress after 1 and 2 years' exposure.

(b) <u>Results and Discussion.</u>

The specimens were examined and tested as those previously reported in R.22/5. The results of micro-examination are given in Tables 1 and 2, and they are very similar to those of the previous series. The results of the tensile test are given in Tables 3.A. to 3.K. along with those of the first series. It will be seen that the results of the two series of tests are almost identical except for those exposed at Site V. (total immersion, sea-water) where the difference in U.T.S. between the new series and old series of both the HE.10 and HE.15 is over 1 ton/in^2. This is due to the localised attack which develops on both alloys after exposure at this site. At all the other sites the difference in U.T.S. is less than 1 ton/in^2.

From these tests it is clear that the original finding that stress had a negligible effect on corrosion damage as judged by the residual strength of the corroded specimens has been confirmed.

Fig.1 shows the original experimental and theoretical curves, suggested by Champion, of the two series of tests for HE.15 and HE.10 specimens exposed at Sheffield, and HE.15 at Hayling Island, taken from R.22/5. The experimental curve of this series of tests has been added, and it will be seen how very closely it follows the other two in each case.

The results of control specimens are given in Table 4 along with those of the previous series. Due to a shortage of material only three control test pieces were tested.

The general conclusions of the tests are all the same as those of the previous tests as given in R.22/5. These are that -

1. Sheffield atmosphere caused the greatest deterioration in properties of both HE.10 and HE.15.

2. The average percentage loss in strength is approximately the same for both alloys, although the average loss in tensile strength is greater for HE.15 than for HE.10. The maximum corrosion is, however, found in isolated specimens of HE.15 showing foliation attack on a macro scale.

3. The results of total immersion tests show localised attack. The results of those at Christchurch show more scatter due to highly localised attack.

The second series of tests also confirm the original results in that severe macro foliation attack starts on some specimens of HE.15 alloy after at least 1 year's exposure. Intercrystalline corrosion of the longitudinal type starts first and is followed by foliation of the surface layers. The attack was most serious at Sheffield. This type of attack is localised, and not necessarily located in that part of the specimens forming the gauge length of the tensile test piece. As in the previous tests one specimen exposed at Sheffield had an exceptionally low U.T.S. which was associated with this foliation attack. Fig.2 is a photograph of this specimen showing the flaking of the surface layers. Due to this type of attack, it is not considered that the exponential type of curve suggested by Champion, and referred to in Fig.1, can be directly applied to the design of structures in this alloy exposed to atmospheric corrosion.

The remaining specimens will be removed after a total of exposure time of four and eight years.

<u>3.2. Effect of Copper content on the corrosion resistance of HE.10.</u>

(a) <u>General</u>.

Eight melts of HE.10 were made with copper contents ranging from 0-0.5% copper. Each melt was made into a billet and cut in half for extrusion purposes. One half of each was pre-heated for 19¼ hours at 470°C. and then extruded from a press pre-heated to 420°C, and the extrusions were press quenched in water at 27°C. About 9" of the front end of each channel section extrusion was removed. Due to the jets of quenching water being some distance from the die orifice, the last few feet of the extrusions never reached the main supply of quenching water and the last five feet of each extrusion were rejected. The chemical composition of each melt is given in Appendix II.

Specimens 6" long were cut from each channel and aged for 8 hours at 175°C. after which they were subjected to laboratory tests and field exposure tests. The results of the 3% NaCl spray laboratory test have already been reported in R.22/6.

Unstressed channel sections were exposed at Sheffield, severe industrial Site I, and Hayling Island, severe marine atmosphere, Site III. One channel of each composition has been removed after 6, 12 and 24 months' exposure. Remaining specimens will be removed after a total of four years.

(b) Results and Discussion.

Table 5 shows the results of tensile tests made on the corroded specimens and also on control specimens. The scatter of results is very considerable and, unlike the previous results on specimens exposed to 3% NaCl spray for a year in the laboratory, there is no clear indication of an effect of copper contents up to 0.47% in increasing corrosion susceptibility. A clearer indication may be found from the results of the 4 year exposure tests. However, as the copper content increased, there was an increased longitudinal tendency and the five alloys containing more than 0.25% copper showed a definite longitudinal micro-foliation type of attack when exposed at Hayling Island, although not at Sheffield. The results of microscopic examination are given in Tables 6 and 7.

Micro-examination of control specimens etched in Kellers etch showed that there was no difference in the structure of those alloys containing 0.088% copper or less. However, a slight banded structure was evident in that alloy containing 0.16% copper, which became more pronounced with increasing copper. This, of course, accounts for the difference in the type of corrosion attack, the longitudinal attack being associated with the banded structure of the higher copper content alloys.

It is well known from work at the B.N.F.M.R.A. on aluminium and its alloys exposed to domestic water supplies that copper in solution can be at least as damaging as copper in the alloy, and the difference between the results of the atmosphere and laboratory tests may be due to wind-and rain-borne heavy metal contamination either from outside sources or from adjacent specimens. The effects of the banded structure in the higher copper alloys might also tend to reduce attack in the first 18 months of test, although this effect would operate in laboratory, as well as field tests. The fact that a longitudinal tendency in form of attack is beginning on some of the higher copper samples suggests that damaging foliation attack might take place on longer term exposure.

3.3. Field Exposure Tests on low manganese and normal manganese H.15 Sheet and Extrusions.

(a) General.

The two casts of dural type alloy containing 0.75% manganese (normal manganese) and 0.08% manganese (low manganese) were cut in half. One portion was extruded to 2" diameter bars and the other forged into slabs which were rolled to sheet. Details of composition, extrusions, forging and rolling, are given in Appendix I. Specimens 12" x $\frac{3}{4}$" x 0.1" were exposed in frames similar to those used for the other exposure tests at Site I (Sheffield), and stressed by constant strain. The sheet specimens were nominally stressed at the maximum design stress - 16 tons/in^2, and the 0.1% proof stress - 24 tons/in^2. The extruded specimens were only stressed at the 0.1% proof stress. Unstressed specimens of both sheet and extrusions were exposed at the same time.

(b) Results and Discussion.

Duplicate specimens of each alloy have been removed, examined and tested after 3, 6 and 12 months' exposure. The tensile test results are given in Table 8, along with those of control specimens, and the micro-examination results in Table 9. Due to the difference in initial tensile properties of the two materials, a direct comparison of the results is not justified. However, it can be seen that there is a much greater loss in strength of the sheet specimens than of the extruded specimens and that the low manganese sheet showed a greater loss in strength than the normal manganese sheet.

These tests show that stress has an important effect on the corrosion damage on sheet specimens. For both the normal manganese and low manganese alloy sheet specimens there was a far greater loss in strength of those specimens exposed at the higher stress, than those exposed at the lower stress which, in turn, was greater than the loss in strength of the unstressed specimens. One of the low manganese sheet specimens nominally stressed at the 0.1% proof stress (24 tons/in^2) was missing after 12 months' exposure, and although the pieces were not found, it has been assumed that it failed by stress corrosion. The other specimen broke at 19.1 tons/in^2, or is less than the initial stress of 24 tons/in^2. The two ends of the specimen were also tested, and broke at 21.7 and 21.4 tons/in^2, with elongations of 2% and 3%, respectively.

Since the specimens are stressed in constant strain by four-point load bending, the stress of the specimens decreases once the elastic limit of the material has been reached. Those specimens at the higher stress showed a permanent set when removed from the jigs, and therefore the actual stress must have decreased during the test to well below the 24 tons/in^2 which was originally applied. The specimens stressed at 16 tons/in^2 did not show a permanent set.

For convenience, specimens were all exposed in the same jigs which had been used for the original field tests, and the same initial stress was applied to both alloys despite the differences in initial mechanical properties of the two materials.

The results of micro-examination, Table 9, show that the loss in tensile strength is broadly associated with the amount and depth of corrosion attack. The low manganese sheet was corroded to a greater depth than the normal manganese sheet, and the sheet specimens showed much more corrosion attack than the extruded specimens. Those sheet specimens stressed at 0.1% proof stress showed a deeper attack than those at the lower (maximum design) stress, which in turn was deeper than the unstressed specimens. The maximum depth of the corrosion attack on the one remaining low manganese sheet specimen nominally stressed at 0.1% proof stress for 12 months was 0.038" or over half the thickness of the specimen.

The stress, however, did not affect the amount or depth of corrosion on the extruded specimens.

On both the sheet and extrusion specimens the scatter of the tensile test results is too great to draw any conclusions as to the variation in rate of attack with time, except in the case of the stressed sheet specimens which all show a marked increase in the rate of attack during the last 6 months of the test. After 3 and 6 months' exposure the corrosion attack was mainly of the pitting type with some intercrystalline corrosion. After 12 months, however, the attack tended to become more longitudinal, accompanied by general sub-grain intercrystalline attack. This type of attack penetrated inwards only on the tension side of the stressed sheet specimens, but on both sides of the extruded stressed specimens.

3.4. Influence of Welding on the Corrosion Resistance of HE.10 and HE.15.

Since it appears likely that welding will destroy directional effects in extrusions it may, therefore, make HE.15 susceptible to stress corrosion. In view of the extensive use of welded aluminium structures a programme of work has been started to determine the effect of welding on both HE.10 and HE.15. Metallic arc welded extruded plates .25" thick, of both HE.10 and HE.15 have been supplied and are being machined into specimens .1" thick suitable for field tests. Some of the original HE.10 jigs have been slightly modified to be able to accommodate the specimens stressed at 4 T/in^2 and 6 T/in^2. The specimens will be exposed at Sheffield (Site I) and at the atmospheric site at Hayling Island (Site III). They will be examined visually after 3 and 6 months and nine specimens of each alloy in each condition of stress, as well as unstressed, will be removed after 1 and 2 years. The remaining nine specimens stressed at 6 tons/in^2 and unstressed specimens will be removed after 4 years.

These field tests should commence in 3-4 months time. At the same time some accelerated stress corrosion laboratory tests will be conducted.

4. LABORATORY TESTS.

4.1. Effect of atmospheres of Various Humidities.

As described in R.22/6 saturated solutions of various salts that would give known relative humidities of the air immediately above them, were placed in boiling tubes. Small pieces of HE.15 and HE.10 were cleaned and suspended above the solution from a cork which fitted loosely into the top of the tube. Four tubes ranging in R.H. from 67% - 92% were thus filled and placed in a container maintained at a steady temperature of 19-22°C.

At the end of a year, there was only a slight difference in the appearance of the HE.15 specimens. Those at the higher humidity atmospheres had a slightly darker appearance and very small amounts of corrosion product were visible on the surface. There was no detectable difference in the HE.10 specimens. After one year's exposure, the specimens were removed, and each was sprayed once with a 3% sodium chloride solution. They were then replaced in the same tubes as previously, and examined after 3, 6 and 12 months.

Even after 3 months, there was an indication that the higher the humidity the greater the corrosion attack, with both HE.10 and HE.15, and this became more pronounced with time. The attack on HE.10 even at 92% R.H. was isolated and resembled worm casts. That on HE.15 was more general.

It seems clear that the relative humidity does have an effect upon the rate of corrosion of aluminium alloys, provided there is some other corroding medium (ie., the chloride ion) present either in the atmosphere or on the aluminium itself. At 67.3% R.H. the attack is very slight, but it becomes increasingly severe up to 92%.

The specimens have been re-sprayed with 3% sodium chloride solution, and again have been sealed in their respective tubes until further examination.

4.2. Effect of Removal of Corrosion Products.

Previous tests (R.22/6) on the effect of removal of corrosion products on HE.15 showed that the corroding conditions were too severe and masked any effect that the removal might have on the rate of corrosion attack.

The extruded specimens, from the original batch of HE.15 channel material, solution heat treated 1 hour at 500°C. and aged 8 hours at 170°C. were sprayed daily with a 3% sodium chloride solution and were kept in a closed cabinet. The corrosion products had been removed from different sets of specimens immediately before spraying at the following intervals.

(a) Daily.

(b) Every three days.

(c) Weekly.

(d) Fortnightly.

This test has been repeated with two modifications. The specimens were suspended outside in the normal atmosphere, and from one set of specimens the corrosion product has not been removed. Five channel specimens were in each set, one of these was hung vertically so that the 3% sodium chloride spray solution could easily drain off the specimens which would be washed by rain and dried by sun. The other specimens were hung horizontally so that the underneath, protected by the flanges, could not be washed or dried as easily.

The results of visual and microscopical examination after two and seven months' exposure, are given in Table 10, and it will be seen that there is still no pronounced difference between any of the specimens. The foliation attack is very localised and developed more quickly on some specimens than on others. In the earlier laboratory tests, the attack was not as localized, and although it started at one or two points on each specimen, it became more general.

The attack resembles, however, the attack at the exposed atmospheric sites more than the previous tests did.

4.3. Simulation of Industrial Atmospheres. Effect of Additions to Humid SO_2 Test.

(a) Previous work and Description of Present Test.

The first series of tests made in order to simulate an industrial atmosphere, by making additions to the humid SO_2 beaker test, has been described in R.22/6, where it was reported that the chloride ion produced an attack resembling that observed with specimens exposed to the industrial atmosphere of Sheffield. Similar specimens have been exposed to a humid SO_2 atmosphere containing various additions of HCl.

The apparatus used has been described in many previous reports (e.g. R.22/5). The additions of 3, 6 and 9 ml. of normal hydrochloric acid were made to each renewed solution and with each SO_2 addition. These were equivalent to .11 gms, .22 gms, and .33 gms HCl, respectively.

Specimens of the original batch of channel of HE.10 and HE.15 in the elevated temperature aged condition were exposed to the three conditions of test. At the end of each exposure period, 3, 6 and 12 months, duplicate specimens in each alloy were removed from each beaker.

The corrosion product was removed by immersion in a Cr_2O_3/H_3PO_4 solution. The specimens were then weighed, and their tensile properties determined. Microsections were also made and examined.

(b) Results and Discussion.

The results of loss in weight, tensile tests and micro-examination are given in Tables 11, 12 and 13, respectively.

The loss in weight determinations are not reliable for the HE.15 specimens exposed for 12 months, due to the foliation attack, since it was impossible to dissolve out the corrosion products without removing the layers of metal between the bands of corrosion. Unfortunately, one specimen of HE.15 exposed to the 3 mls. of HCl for 3 months dipped into the solution and the loss in weight is unduly high. Of the remaining results, there has been a greater loss in weight of the specimens exposed to the 6 mls. of HCl than to the 9 mls. which, in turn, is greater than those exposed to 3 mls. The corrosion attack was of the foliation and pitting type, and resembled that of the specimens exposed at Sheffield, for 2 years. The attack, however, was much deeper. The tensile tests showed that there has been a greater loss of ultimate after one year's exposure to the SO_2 and HCl beaker test than after 2 years' exposure to the industrial atmosphere at Sheffield, and that there seems to be no substantial difference between the specimens exposed to various amounts of HCl. The general conclusion is that increasing the amount of HCl in the range 3 - 9 mls. does not increase the rate of corrosion attack on HE.15, and that the rate of attack is about 5-6 times greater for the humid SO_2 and HCl test than for the exposure tests at Sheffield, as judged by tensile tests.

There was a much smaller loss in weight for the HE.10 specimens than for the HE.15. The values are slightly larger after 6 months than 3 months, but after 12 months the loss of weight is about double that after 6 months. Increasing the HCl added from 3 - 9 mls.

seems to have no obvious effect upon the rate of corrosion attack as judged by any of the three methods used. The micro-examination showed that the type, amount and depth of attack resembled that on HE.10 specimens exposed at Sheffield for 2 years.

Compared with field tests, the HE.10 material shows much less attack than H.15 material, whereas there was little difference in the two materials after 2 years' atmospheric exposure, but it is possible that a better relative correlation between the corrosion behaviour of the two alloys will emerge from longer term field tests (4 and 8 years) and it may be that the SO_2 HCl test will prove a useful accelerated test. The high humidity of most laboratory tests appears to accelerate the foliation type of attack.

4.4. Effect of Various Heat Treatments on Corrosion of Normal and Low manganese alloys.

(a) General.

Sheet (.036" and .05") specimens of the low and normal manganese alloys (Appendix I) as well as extrusion specimens cut as discs .1" in thickness of the 2" diameter bar were heat treated at 500°C. and aged at 170°C. for various lengths at times as follows:-

Sheet specimens .05" and .036"

	Heat treated 4 hours at 500°C.	Aged 4 hours at 170°C.
	4 " " "	24 " " "
	4 " " "	168 " " "
	24 " " "	4 " " "
.05" only.	24 " " "	24 " " "
	24 " " "	168 " " "

Extruded specimens 1	hour	at	500°C.	Aged 4	hours	at	170°C.
1	"	"	"	24	"	"	"
1	"	"	"	168	"	"	"
4	"	"	"	4	"	"	"
4	"	"	"	24	"	"	"
4	"	"	"	168	"	"	"
24	"	"	"	4	"	"	"
24	"	"	"	24	"	"	"
24	"	"	"	168	"	"	"

The specimens were sprayed once daily with a 3% sodium chloride solution and were examined visually after 1, 3 and 6 months, at which times microsections were prepared and examined. The results of the visual examination are given in Tables 14, 15 and 16, and of the microscopical examination in Tables 17, 18 and 19.

(b) Results and Discussion.

Since the surface of the extruded specimens in contact with the 3% sodium chloride spray is normal to the extrusion direction, the corrosion attack penetrated inwards as pits, or fine hairline cracks, parallel to the extrusion direction, and after 6 months it had penetrated in some cases over half the thickness of the specimen. This same type of attack is described as "foliation or layer corrosion" in other sections of this report, since then it runs parallel to the surface of the specimen in contact with the corroding medium and is described either as pitting or layer attack in Tables 17 - 19, depending upon the width of the attack. There appears to be little or no difference between the two alloys as judged by visual examination, although the attack on the low manganese alloy extruded discs was perhaps more general than on the normal manganese alloy specimens.

Micro-examination also shows that there is a little difference in the attack on the extruded specimens of the two alloys. The results agree with previous work (R.22/6) on effect of heat treatment on HE.15 that the length of time of ageing has more effect upon the rate of corrosion attack than the time of heat treatment. There was, in general, more pitting and fine subgrain attack on the normal than on the low manganese extruded specimens. There is some evidence that the amount of attack decreases slightly with increasing time of heat treatment, and a pronounced evidence that the amount of attack decreases with increasing time of ageing. There is, however, a greater improvement by increasing the time of ageing from 4 to 24 hours, than from 24 to 168 hours. Those specimens heat treated for 24 hours and aged for 24 and 168 hours showed the least amount and depth of attack. The attack on the low manganese alloy appeared to be worse than on the normal manganese alloy.

The same relationship between time of heat treatment and ageing with corrosion attack was true for the sheet specimens as well, although the time of heat treatment had a greater effect than upon the extruded specimens. The intercrystalline corrosion attack showed slightly more longitudinal tendency on the normal manganese containing alloy than on the low manganese containing alloy, especially on the 0.05" sheet.

5. STRESS CORROSION.

5.1. Determination of Safe Level of Stress for H15.

The results of stress corrosion tests on H15 studying the effect of manganese on the directionality shown by extrusions (R.22/7) has shown that although HE.15 is not susceptible to stress corrosion when stressed in the direction of extrusion, it is very susceptible when stressed transverse to the extrusion direction. Sheet specimens are also very susceptible to stress corrosion. It is important, therefore, to determine if there is a safe level of stress below which stress corrosion will not occur in H15 sheet and extrusions when stressed normal to the extrusion direction.

The results, to date, are given in Table 20. The material used for this section of work was the normal manganese alloy referred to in Appendix I. The specimens were stressed in direct tension by means of lever operated jigs.

The specimens were small cylindrical bar type test pieces with threaded ends, and a gauge length of 1" and diameter of 0.179". The specimens were in a vertical position and their gauge lengths were sprayed once daily with a 3% sodium chloride spray. The specimens were made of the normal manganese alloy as described in Appendix I. The sheet specimens were machined from .2" thick sheet so that the gauge length was longitudinal to the direction of rolling. Previous work (R.22/7) has shown that the direction of rolling has no effect upon the stress corrosion properties of this material. The extruded specimens were machined from the 2" diameter extruded bar so that the longitudinal axis was normal to the longitudinal axis or extrusion direction of the bar.

Comparing the two series of results given in Table 20, the stress that can be sustained is slightly higher for the sheet material than for the transverse extruded material. It has been shown (R.22/7) that specimens cut from the same bar with the longitudinal axis parallel to the longitudinal axis or extrusion direction of the bar were not susceptible to stress corrosion in bend tests and failed in direct tension after 125 days stressed at 16 tons/in^2, 60 days stressed at 20 tons/in^2 and 77 days stressed at 24 tons/in^2. There are some tests in each material which have recently been started and which have been noted in Table 20. Although the results are incomplete the fact that failure has taken place at stresses as low as 6 tons/in^2 in transverse specimens from extrusions, and 8 tons/in^2 in sheet, suggests that there is virtually no safe limit of stress for these materials. Any structural part must be expected to carry loads of this order, and even on parts which do not carry any externally applied load the internal stresses must approach these values.

5.2. Prevention of Stress Corrosion by Protective Coatings.

It is obvious that some kind of protection is necessary before H15 alloy sheet and extrusions stressed normal to the direction of stressing can safely be used for structural work in corrosive atmospheres, and some preliminary tests have been carried out in order to see if protection can be given by metallic sprayed or painted coatings which if anodic to the basis duralumin will protect it sacrificially similarly to cladding on sheet.

Sheet specimens of the normal manganese alloy .036" thick have been sprayed with .002" coatings of commercial purity aluminium (99.7) aluminium/1% zinc, and zinc, and some were painted with two brush coats of metallic zinc paint. These were stressed in a cantilever or one point load type of jig, and sprayed once daily with a 3% sodium chloride solution. This work has previously been described in R.22/8.

The results are given in Table 21. There has been no failure of specimens coated with aluminium or aluminium/1% zinc after 476 days at 18 tons/in^2, and 265 days at 24 tons/in^2. The zinc sprayed coatings give less protection and the metallic zinc paint still less. Even the latter does, however, greatly lengthen the life of the sheet specimens.

Tests are also being made on HS.15 specimens which have been given two different types of painting schemes, with and without scratch marks. Since there was not enough of the normal manganese alloy material available and different material was necessary, some specimens have been sprayed with aluminium to give a comparison between these tests and the previous ones. No results have yet been obtained.

Some HE.15 channel specimens from the original batch of material are being given sprayed coatings of aluminium, and similar specimens will be given two brush coats of metallic zinc paint. These unstressed specimens will be sprayed once daily with a 3% sodium chloride solution and kept in a closed cabinet to see if these coatings will also prevent the foliation type of attack on extruded specimens.

VI. SUMMARY AND CONCLUSIONS.

1. HE10 and HE15 exposed to field corrosion tests at five sites for periods of 12 and 24 months confirm previous findings.

2. Field tests on HE10 alloy with added copper contents up to 5% are inconclusive after 24 months' exposure. Increasing copper content increases directionality of attack.

3. Comparative field tests on sheet and extruded H15 alloy with low and normal manganese contents for periods up to 12 months show that -

(a) Sheet material is subject to stress corrosion in these conditions whereas extruded material stressed parallel to the direction of extrusion is not.

(b) There is a slightly greater amount of attack with the low manganese material.

4. In laboratory tests it has been shown -

(a) That relative humidity is a very important factor in determining rate of attack, and a high humidity strongly favours foliation type of attack in HE15 alloy.

(b) That periodic removal of corrosion products during salt spray testing does not influence rate of attack.

(c) That the HE10 alloy is much more resistant than HE15 to the humid SO_2 test with HCl additions, and that foliation attack develops rapidly in the HE15 alloy in this test.

(d) That the effect of variations in solution and ageing heat treatment times on normal and low manganese H15 sheet and extruded unstressed specimens does not markedly affect rate of corrosion in salt spray, but there is some tendency for corrosion to decrease with increasing time of solution heat treatment, and also to decrease with increasing time of ageing. This effect becomes more marked in H15 sheet.

Manganese tends to decrease the rate of attack and causes more marked directionality in both sheet and extrusions.

(e) Stress corrosion failures in salt spray have taken place in H15 sheet at a stress of 8 tons/in^2 and in H15 extrusion stressed normal to the extrusion direction at a stress of 6 tons/in^2. It is doubtful if a practical safe level of stress exists, particularly in the specimens cut transverse from extrusions.

(f) Very promising results have been obtained on specimens of H15 sheet specimens sprayed with commercial purity aluminium and aluminium/1% zinc alloy. No failures have so far occurred in salt spray with stresses as high as 24 tons/in^2.

VII. WORK IN HAND.

1. Field tests will continue and specimens will be examined after exposure times of 4 and 8 years at five sites in HE10 and HE15 specimens.

2. HE10 specimens with copper contents up to 0.5% will be examined after exposure for 4 years at two sites.

3. Preliminary examination and cutting of specimens from metallic arc-welded HS10 and HS15 plate are complete, and field exposure and laboratory corrosion tests will start shortly.

4. Work will continue on the correlation between laboratory and field corrosion tests.

5. Laboratory salt spray tests to determine safe level of stress for HS15 and HE15 specimens cut transversely from extrusions will continue.

6. Laboratory tests will continue on the influence of protective coatings on tendency to stress corrosion. These will include painting of sheet and metal spraying.

VIII. FUTURE WORK.

1. Layer Corrosion.

It is strongly recommended that work be put in hand to study the mechanism of layer corrosion, particularly to determine whether this tends to proceed at an accelerating rate. Since layer corrosion appears to proceed along planes of heterogeneity, efforts should be made to correlate this with heterogeneity in the original ingot and to determine the composition of layers which are preferentially attacked and which are resistant.

2. Susceptibility of other alloys.

In view of the susceptibility of the H15 type alloys to layer and stress corrosion, it is recommended that a programme of exposure tests similar to that already carried out on the H10 and H15 alloys be undertaken with the aluminium/copper/cadmium and aluminium/zinc/magnesium alloys.

EAGL/WAB/EMF
5.11.53.

TABLE 1.

MICROSCOPICAL EXAMINATION OF HE15 SPECIMENS AFTER 12 AND 24 MONTHS' EXPOSURE.

N.B. The expression "foliation attack" in this table signifies that this form of attack appears on a micro and not necessarily on a macro scale.

Site	Period of Exposure	Stressed at Design Stress	Stressed at 0.1% Proof Stress.	Unstressed
I Sheffield	12 months	General shallow pitting and general foliation attack.		
		M.D.* 0.008	M.D. 0.007	M.D. 0.005
	24 months	General foliation attack.		
		M.D. 0.007	M.D. 0.010	M.D. 0.008
II Euston	12 months	General foliation attack.		
		M.D. 0.004	M.D. 0.004	M.D. 0.005
	24 months	General foliation attack.		
		M.D. 0.007	M.D. 0.006	M.D. 0.006
III Hayling Island Atmospheric (Marine)	12 months	General foliation attack.		
		M.D. 0.008	M.D. 0.007	M.D. 0.005
	24 months	General foliation attack.		
		M.D. 0.009	M.D. 0.008	M.D. 0.005
V Hayling Island Total Immersion	12 months	Slight isolated attack some specimens attack negligible.		
		M.D. 0.002	M.D. 0.001	M.D. 0.001
	24 months	Isolated foliation attack.		No unstressed
		M.D. 0.006	M.D. 0.006	
VII Christchurch Total Immersion	12 months	Slight isolated foliation attack, some specimens attack negligible.		
		M.D. 0.003		M.D. 0.001
	24 months	Isolated foliation attack, some specimens attack negligible.		
		M.D. $<$ 0.003	M.D. 0.009	M.D. 0.005

* M.D. = maximum depth

TABLE 2.

MICROSCOPICAL EXAMINATION OF HE10 SPECIMENS AFTER 12 AND 24 MONTHS' EXPOSURE.

Site	Period of Exposure	Stressed at Design Stress	Stressed at 0.1% Proof Stress.	Unstressed
I Sheffield	12 months	General intercrystalline corrosion with some intercrystalline pitting.		
		M.D.* 0.012	M.D. 0.014	M.D. 0.010
	24 months	General intercrystalline corrosion with some isolated attack.		
		M.D. 0.010	M.D. 0.016	M.D. 0.008
II Euston	12 months	General intercrystalline corrosion.		
		M.D. 0.008	M.D. 0.016	M.D. 0.010
	24 months	General intercrystalline corrosion.		
		M.D. 0.008	M.D. 0.008	M.D. 0.008
III Hayling Island Marine Atmosphere.	12 months	General intercrystalline corrosion.		
		M.D. 0.012	M.D. 0.009	M.D. 0.010
	24 months	General intercrystalline corrosion.		
		M.D. 0.013	M.D. 0.013	M.D. 0.009
V Hayling Island Total Immersion	12 months	Isolated intercrystalline corrosion.		
		M.D. 0.016	M.D. .005	M.D. 0.016
	24 months	Isolated intercrystalline corrosion.		
		M.D. 0.003	M.D. 0.0021	M.D. 0.005
VII Christchurch Total Immersion	12 months	Isolated intercrystalline corrosion.		
		M.D. 0.018	M.D. 0.013	Some rounded pits. M.D. 0.020
	24 months	Isolated intercrystalline corrosion.		
		M.D. 0.011	M.D. 0.021	M.D. 0.020

* M.D. = maximum depth.

TABLE 3.A.

TENSILE TESTS ON SPECIMENS AFTER 12 MONTHS EXPOSURE AT SITE I (SHEFFIELD).

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd	U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd
Design Stress.											
16.5	8	16.8	9			29.7	4	27.7	7		
16.1	8	16.6	11	16.4	16.6	29.0	6	29.3	6	28.7	28.4
16.6	10	16.5	10			27.3	6	28.2	9		
0.1% Proof Stress.											
16.9	8	15.9	9			27.4	8	29.5	8		
16.0	6	16.8	9	16.4	16.5	26.6	8	27.1	5	26.7	28.6
16.3	6	16.7	9			26.1	6	29.3	6		
Unstressed.											
17.0	8	18.6	13			28.3	6	28.5	9		
17.2	8	18.7	12	17.2	18.4	27.8	6	28.5	9	28.0	28.7
17.4	10	17.9	10			27.9	8	29.0	9		
				16.7	17.2					27.8	28.6

TABLE 3.B.

TENSILE TESTS ON SPECIMENS AFTER 12 MONTHS EXPOSURE AT SITE II (EUSTON ST.).

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd	U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd
Design Stress											
17.6	10	17.5	11			28.9	8	30.4	8		
18.2	8	17.7	13	17.8	17.6	28.6	10	28.8	9	29.0	29.3
17.5	8	17.6	11			29.4	6	28.6	9		
0.1% Proof Stress											
17.5	8	18.4	10			30.1	6	28.4	9		
17.7	8	18.3	10	17.6	18.3	30.1	7	29.9	7	28.8	29.5
17.6	10	18.1	9			28.2	8	30.3	7		
Unstressed											
17.8	12	18.5	9			30.2	6	29.5	9		
18.1	12	18.8	10	17.9	18.7	29.7	8	29.0	8	29.7	29.7
17.8	12	18.9	10			29.2	8	30.6	8		
				17.8	18.2					29.4	29.5

TABLE 3.C.

TENSILE TESTS ON SPECIMENS AFTER 12 MONTHS EXPOSURE AT SITE III (HAYLING ISLAND, MARINE ATMOSPHERE).

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd	U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd
Design Stress											
18.8	7	18.2	9			28.5	7	28.7	8		
18.5	7	18.6	9	18.5	18.3	27.0	9	27.4	8	28.4	28.9
18.1	8	18.0	9			29.7	7	29.7	10		
0.1% Proof Stress											
17.8	10	18.4	7			29.9	7	26.5	10		
17.7	8	18.3	7	17.8	18.3	27.2	5	28.6	8	28.6	27.4
17.9	8	18.3	8			28.7	8	27.2	10		
Unstressed											
18.0	8	18.0	10			29.2	7	29.0	7		
18.2	9	17.8	10	18.2	17.7	31.0	7	30.0	7	30.3	28.9
18.4	9	17.2	8			30.7	6	27.6	4		
				18.2	18.1					28.8	28.4

TABLE 3.D.

TENSILE TESTS ON SPECIMENS AFTER 12 MONTHS EXPOSURE AT SITE V (HAYLING ISLAND TOTAL IMMERSION).

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in2	El%	U.T.S. T/in2	El%	1st	2nd	U.T.S. T/in2	El%	U.T.S. T/in2	El%	1st	2nd
Design Stress											
17.7	12	19.0	16			31.6	8	30.2	12		
17.6	12	18.0	10	17.7	18.6	30.5	12	30.0	11	30.7	31.5
17.7	15	17.7	15			30	9	34.2	8		
0.1% Proof Stress											
18.6	12	19.6	12			31.1	8	32.1	9		
19.0	12	19.4	12	18.9	19.4	31.1	10	32.0	10	31.3	32.0
19.0	12	19.3	12			31.8	9	32.0	10		
Unstressed											
18.3	12	18.5	12			29.5	10	31.1	9		
18.4	8	18.4	15	18.3	18.2	30.4	10	30.0	10	30.1	30.5
18.3	13	17.7	10			30.3	9	30.5	9		
				18.3	18.7					30.7	31.3

TABLE 3.E.

TENSILE TESTS ON SPECIMENS AFTER 12 MONTHS
EXPOSURE AT SITE VII (CHRISTCHURCH
TOTAL IMMERSION.

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd	U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd
Design Stress											
16.4	8	14.9	2			29.8	-	30.7	10		
15.7	4	16.2	3	15.5	15.5	26.2	5	31.0	10	28.3	30.6
14.4	4	15.5	4			28.8	8	30.0	10		
0.1% Proof Stress											
15.2	4	17.8	15			29.1	8	30.9	11		
15.5	4	18.6	5	16.3	18.3	29.6	8	29.7	4	29.5	30.5
18.1	10	18.6	6			29.9	8	30.8	10		
Unstressed											
19.4	13	16.2	4			31.7	6	31.1	9		
17.4	5	16.5	6	18.3	16.2	30.1	10	30.3	7	30.1	30.4
18.1	14.0	15.9	5			28.4	8	29.9	10		
				16.7	16.7					29.3	30.5

TABLE 3.F.

TENSILE TESTS ON SPECIMENS AFTER 24 MONTHS EXPOSURE AT SITE I (SHEFFIELD).

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in²	El%	U.T.S. T/in²	El%	1st	2nd	U.T.S. T/in²	El%	U.T.S. T/in²	El%	1st	2nd
Design Stress											
16.8	6	17.7	10			28.0	7	28.9	7		
16.5	11	16.9	9	16.9	17.1	29.4	7	30.2	5	28.9	29.4
17.3	8	16.6	12			29.2	6	29.0	8		
0.1% Proof Stress											
16.8	8	16.2	9			29.3	4	26.1	5		
16.3	10	16.5	9	16.6	16.3	28.3	4	22.2	x	28.3	25.4
16.6	9	16.1	9			27.4	6	27.8	6		
Unstressed											
16.7	9	17.1	12			26.6	4	28.1	6		
17.2	10	17.0	10	16.9	17.0	20.3	x	27.8	5	25.2	28.2
16.8	10	16.9	11			28.8	4	28.7	6		
				16.8	16.8					27.5	27.6

x Broke outside gauge length.

TABLE 3.G.

TENSILE TESTS ON SPECIMENS AFTER 24 MONTHS EXPOSURE AT SITE II (EUSTON ST.)

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd	U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd
Design Stress											
17.8	11	17.4	13			29.6	8	27.8	9		
17.5	11	17.6	12	17.6	17.3	28.6	9.5	30.0	8	29.4	29.4
17.4	12	17.0	12			28.7	10	30.3	8		
0.1% Proof Stress											
17.4	10	17.8	12			30.7	10	29.5	8		
17.3	10	17.9	12	17.4	17.9	30.5	6	29.2	7	30.6	29.1
17.4	-	18.1	10			30.5	7.5	28.5	7		
Unstressed											
17.8	11	17.5	12			29.8	8	28.7	8		
18.0	11	18.1	12	17.9	17.8	30.0	9	30.0	8	30.0	29.2
17.9	11	17.7	12			30.2	8	29.0	9		
				17.7	17.7					30.0	29.2

TABLE 3.H.

TENSILE TESTS ON SPECIMENS AFTER 24 MONTHS EXPOSURE AT SITE III (HAYLING ISLAND, MARINE ATMOSPHERE).

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd	U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd
Design Stress											
17.8	8	17.1	10			29.0	5	28.9	7		
17.9	10	18.1	10	17.8	17.7	28.2	7	29.1	3	28.7	29.5
18.0	10	17.8	9			28.9	6	30.4	9		
0.1% Proof Stress											
17.1	8	18.3	7			28.9	6	27.5	7		
17.2	10	17.8	7	17.3	17.7	28.1	4	30.3	8	28.7	28.4
17.6	10	17.1	11			29.2	6	27.5	5		
Unstressed											
17.6	10	19.1	11			29.2	8	29.7	8		
18.4	10	18.6	10	17.7	18.8	23.8	4	28.9	8	27.4	29.0
17.2	11	18.6	8			29.2	7	28.4	10		
				17.6	18.1					28.3	29.0

TABLE 3.J.

TENSILE TESTS ON SPECIMENS AFTER 24 MONTHS EXPOSURE AT SITE V (HAYLING ISLAND, TOTAL IMMERSION.)

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd	U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd
Design Stress											
17.3	15	19.4	13			30.0	12	31.8	12		
17.5	14	19.7	9	17.4	19.4	31.4	9	31.4	8	30.9	31.3
17.3	7	19.0	13			31.4	9	30.6	10		
0.1% Proof Stress											
18.1	10	19.4	9								
18.2	13	19.6	11	18.3	19.2	29.4	11	31.3	10		
18.6	5	18.5	4			30.4	10	31.2	9	29.6	26.8
						29.0	11	17.9*	2		
Unstressed											
18.0	14	19.5	12								
17.1	-	19.3	12	17.6	19.4	No Unstressed					
17.6	10	19.4	13								
				17.8	19.3					30.3	29.1

*broke at area of severe localized attack.

TABLE 3.K.

TENSILE TESTS ON SPECIMENS AFTER 24 MONTHS EXPOSURE AT SITE VII (CHRISTCHURCH TOTAL IMMERSION.)

HE 10						HE 15					
1st Series		2nd Series		Average U.T.S.		1st Series		2nd Series		Average U.T.S.	
U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd	U.T.S. T/in^2	El%	U.T.S. T/in^2	El%	1st	2nd
Design Stress											
16.6	7	17.9	2			27.2	5	30.8	9		
16.6	-	16.7	6	15.5	17.1	28.1	8	30.8	7	28.8	30.3
13.4	5	16.8	4			31.5	11	29.3	6		
0.1% Proof Stress											
18.8	9	19.6	14			30.8	9	31.0	9		
18.4	8	17.4	4	18.5	18.3	30.2	6	31.6	9	30.4	31.2
18.4	6	17.9	10			30.2	8	30.9	10		
Unstressed											
17.8	5*	17.6	9			31.1	9	30.0	9		
18.9	12	14.8	4	18.4	16.9	31.4	8	29.6	8	30.8	30.2
18.6	8	18.3	13			29.8	9	30.9	5		
				17.4	17.4					30.0	30.6

*Fractured at deep pit.

TABLE 4.

TENSILE TESTS ON CONTROL SPECIMENS AFTER 12 and 24 MONTHS.

12 months				24 months.			
1st Series.		2nd Series.		1st Series.		2nd Series.	
U.T.S. T/in^2	El %	U.T.S. T/in^2	El %	U.T.S. T/in^2	El %	U.T.S. T/in^2	El %
				HE. 10.			
18.6	12	18.9	12	18.8	8	17.7	13
17.7	12	19.2	12	18.7	9	17.1	13.5
19.2	12	19.2	12	19.2	9	17.7	13.5
19.0	12			17.6	10		
18.8	10			17.7	11		
18.8	8			17.8	9		
				18.7	12		
				18.9	8		
				18.7	10		
Average		Average		Average		Average	
18.7	11	18.1	12	18.5	9.5	17.5	14
				HE 15.			
29.9	8	30.7	8	30.1	8	29.7	10
33.4	6	29.8	8	31.0	9	31.2	10
30.0	8	31.6	8	31.7	9	29.4	8
30.4	10			31.2	10		
32.4	10			31.8	11		
31.3	6			30.9	9		
29.0	11			30.2	12		
30.5	11			31.4	8		
28.4	12			30.4	10		
Average		Average		Average		Average	
30.6	9	30.7	8	31.0	9.6	30.1	9

TABLE 5.

TENSILE TESTS ON HE10 SPECIMENS CONTAINING VARIOUS AMOUNTS OF COPPER AFTER 1 AND 2 YEARS' EXPOSURE AT SHEFFIELD (SITE I) AND HAYLING ISLAND (SITE III) AND CONTROLS.

% Copper	Controls				Sheffield				Hayling Island			
	1 year		2 years		1 year		2 years		1 year		2 years	
	UTS T/in^2	El. %	UTS T/in^2	El. %	UTS T/in^2	El. %	UTS T/in^2	El. %	UTS T/in^2	El. %	UTS T/in^2	El. %
< 0.01	18.8	14	18.9	16	18.0	16	17.7	12	18.4	12	18.9	12
	18.9	16	19.0	15	17.8	14	17.6	12	18.3	13	18.8	10
	18.7	14	18.9	15	17.8	13	17.3	11	18.4	13	18.4	10
0.022	18.1	15	17.8	17	16.6	16	16.5	14	17.5	12	16.8	11
	17.9	15	17.8	18	16.7	15	16.4	14	17.3	15	17.6	13
	18.2	15	17.5	17	16.3	12	16.4	13	17.4	15	17.4	12
0.030	19.4	14	19.7	17.5	17.9	-	16.6	6	18.3	11	17.0	9
	19.4	14	20.3	15	17.7	11	17.5	8	18.7	11	16.8	7
	19.4	14	20.3	15	17.6	10	17.1	8	18.7	10	17.4	12
0.088	18.0	15	17.75	17	15.3	12	16.0	13	16.1	10	17.6	12
	17.6	17	17.8	17	15.3	12	16.0	11	16.0	11	17.9	12
	18.3	16	17.9	14	15.2	10	15.8	18	16.0	11	17.9	12
0.160	20.4	16	20.5	17	18.4	13	18.6	12	19.1	9	19.0	10
	20.3	16	20.6	17	18.6	12	18.3	10	18.5	11	19.0	10
	20.6	16	20.4	17	18.1	12	18.5	13	19.3	12	18.4	11
0.21	20.4	16	20.1	18	18.9	14	17.7	13	18.8	10	18.7	14
	20.3	16	20.4	16.5	19.1	15	16.9	10	19.7	15	18.9	13
	20.2	16	19.9	18.5	18.3	12	18.1	13	19.3	12	19.4	13
0.32	20.0	16	20.0	18	17.8	15	17.7	15	18.2	11	17.7	14
	20.0	16	20.0	18	18.2	16	17.7	12	18.3	12	17.0	10
	20.0	16	20.0	19	17.7	14	17.5	11	17.8	9	17.2	10
0.47	20.7	16	21.3	19	19.3	14	18.9	14	18.8	11	18.6	15
	20.8	16	21.7	17	19.1	15	18.5	14	18.7	13	18.6	10
	20.8	17	21.6	17	18.8	14	18.9	13	18.8	12	17.1	10

TABLE 6.

MICROSCOPICAL EXAMINATION OF HE10 SPECIMENS CONTAINING VARIOUS AMOUNTS OF COPPER AFTER 1 AND 2 YEARS' EXPOSURE AT SHEFFIELD, SITE 1.

% Copper	1 year	2 years
<.01	General i.c.* and pitting. M.D.° 0.015"	General i.c. and pitting. M.D.° 0.013"
0.022	General i.c. and pitting. Slight micro foliation. M.D. 0.010".	General i.c. and pitting. M.D. 0.013"
0.030	General i.c. and pitting. M.D. 0.016"	General i.c. and pitting. M.D. 0.012"
0.088	General i.c. and pitting. M.D. 0.014"	General i.c. and pitting. M.D. 0.011"
0.160	General i.c. and pitting. M.D. 0.010"	General i.c. and pitting. M.D. 0.010"
0.21	General i.c. and pitting. M.D. 0.010"	General i.c. and pitting. M.D. 0.015"
0.32	General i.c. and pitting. M.D. 0.012"	General i.c. and pitting. M.D. 0.016"
0.47	General i.c. and pitting. M.D. 0.011"	General i.c. and pitting. M.D. 0.019"

* i.c. = intercrystalline corrosion

° M.D. = maximum depth

TABLE 7.

MICROSCOPICAL EXAMINATION OF HE10 SPECIMENS CONTAINING VARIOUS AMOUNTS OF COPPER AFTER 1 AND 2 YEARS' EXPOSURE AT HAYLING ISLAND. MARINE ATMOSPHERE SITE III.

% Copper	1 year	2 years
<0.01	Slight general i.c.* M.D.o 0.009"	Slight general i.c. M.D. 0.012"
0.022	Slight general i.c. with some isolated more severe areas. M.D. 0.012"	General i.c. M.D. 0.012"
0.030	Slight general i.c. and pitting. M.D. .011"	General i.c. M.D. 0.015"
0.088	Slight general i.c. M.D. 0.011"	General i.c. M.D. 0.013"
0.160	Slight general i.c. with some isolated severe areas longi-tudinal tendency. M.D. 0.016"	General i.c. M.D. 0.011"
0.21	Slight general i.c. with isolated small pits longitudinal tendency. M.D. 0.009"	General i.c. M.D. 0.011"
0.32	Slight i.c. rather isolated pits. M.D. 0.015"	General i.c. longitudinal tend-ency. M.D. 0.011"
0.46	General fine i.c. with slight tend-ency to foliation. M.D. 0.012"	General i.c. longi-tudinal tendency. M.D. 0.016"

* i.c. = intercrystalline corrosion
o M.D. = maximum depth

TABLE [illegible].

TENSILE TESTS ON LOW MANGANESE AND HIGH MANGANESE H15 SHEET AND EXTRUSION SPECIMENS. EXPOSED AT SITE I (SHEFFIELD)

Material	Nominal Stress	3 months U.T.S. T/in^2.	3 months El. %	6 months U.T.S. T/in^2	6 months El. %	12 months U.T.S. T/in^2	12 months El. %
Sheet Low Manganese	Design Stress $16T/in^2$	27.3 28.5	5 7	27.9 28.0	7 7	23.6 23.7	2 4
Controls UTS T/in^2 El. % 28.3 10 29.1 10	.1% P.S. $24T/in^2$	28.5 28.8	9 7	27.7 27.8	6 6	19.1 specimen missing presumed failed.	1
	Un-stressed	28.2 28.0	7 7	27.9 27.8	6 5	26.5 25.1	6 3
Normal Manganese	Design Stress $16T/in^2$	31.2 31.2	8 8	31.0 30.8	8 8	28.2 28.4	2 3
Controls UTS T/in^2 El. % 33.5 8 32.3 8	.1% P.S. $24T/in^2$	30.9 31.5	7 8	30.8 30.4	8 8	26.2 25.3	1 1
	Un-stressed	30.8 31.2	7 7	30.5 30.2	8 8	29.6 29.0	5 4
Extrusion Low Manganese	.1% P.S. $24T/in^2$	23.5 28.0*	12 5	22.5 29.1*	12 6	24.7* 22.9	3 12
Controls UTS T/in^2 El. % 23.7 11 25.6 10 29.9* 8	Un-stressed	22.9 28.6*	10 8	28.3* 27.0*	5 8	22.7 27.6*	10 5

Cont'd....

TABLE 8 (CONT'D).

Material	Nominal Stress	3 months U.T.S. T/in^2	3 months El. %	6 months U.T.S. T/in^2	6 months El. %	12 months U.T.S. T/in^2	12 months El. %
Normal Manganese	.1% P.S. $24T/in^2$	31.6 32.0	5 7	31.4 31.6	6 6	28.3 28.7	3 3
Controls UTS T/in^2 El. % 33.5 8 32.3 8	Un-stressed	29.5 30.7	3 6	30.1 30.4	4 4	29.7 29.3	4 5

* See Notes and Table 8A.

* Note (Table 8). The scatter of results both in the control specimens and in the corroded specimens has been found to be due to marked differences in the microstructure of the specimens which can be broadly divided into two distinct types. The one type of specimen indicated by * has been found not to have recrystallized and to possess a relatively small grain size. The remaining specimens are recrystallized and generally large grained. In corroded specimens marked * the attack is of the sub-grain type and the other large grained specimens show no sub-grain attack. The mechanical test figures were checked on additional specimens cut from the ends of original stressed specimens, one end of the test piece being just outside the zone of uniform stress. No material was available from the unstressed specimens. The results together with microscopic examination are given in Table 8A. These differences in microstructure and properties are presumably due to differences in degree of working in extrusion on material in different positions of the original 2" diameter extruded bar from which these specimens were cut.

TABLE 8A.

Specimen	Original Tensile Test U.T.S. tons/in^2	Original Tensile Test El. %	Check test from offcut U.T.S. tons/in^2	Check test from offcut El. %	Micro-examination
Stressed at 24 tons/in^2 0.1% Proof Stress and corroded 3 months	23.5	12	23.6	12	Recrystallized large grain no sub-grain attack. A.
	28.0	5	30.3	7	Small grain sub-grain attack. B.
As above but corroded for 6 months	22.5	12	23.0	12	As A.
	29.1	6	29.5	7	As B.
As above but corroded for 12 months	24.7	3	26.2	4	As B.
	22.9	12	22.2	12	As A.
Unstressed corroded 3 months	22.9	10	-		As A.
	28.6	8	-		Intermediate between A & B.
Unstressed corroded 6 months	28.3	5	-		As B.
	27.0	8	-		Intermediate between A & B.
Unstressed corroded 12 months	22.7	10			As A.
	27.6	5			As B.

TABLE 9.

MICROSCOPICAL EXAMINATION OF LOW MANGANESE AND LOW MANGANESE H15 SHEET AND EXTRUSION SPECIMENS EXPOSED AT SITE I (SHEFFIELD).

Material	Stress	3 Months	6 Months	12 Months
Sheet	Design	Slight pitting general i.c. M.D.° .008"	General shallow i.c. pitting. M.D. .008"	i.c. with longitudinal tendency on compression side but penetrating inwards on tension side. M.D.Design .028" M.D. .1%P.S. .03 "
Low Manganese	.1% P.S.	General i.c. M.D. .010"	General shallow i.c. pitting. M.D. .010"	
	Un-stressed	Rather isolated i.c. slight pitting. M.D. .010"	General shallow i.c. pitting. M.D. .010"	General i.c. M.D. .013"
Normal Manganese	Design and .1% P.S.	Slight general pitting, and isolated i.c. M.D.Design .004" M.D. .1%P.S.004"	General shallow i.c. pitting. M.D.Design .004" M.D. .1% P.S.006"	i.c. with longitudinal tendency on compression side but penetrating inwards on tension side. M.D.Design .015" M.D. .1%P.S .020"
	Un-stressed	General slight pitting and slight i.c. M.D. .005"	General shallow i.c. pitting. M.D. .007"	General shallow pitting and longitudinal i.c. M.D. .014"

Cont'd....

TABLE 9 (CONT'D).

Material	Stress	3 Months	6 Months	12 Months
Extrusion				
Low Manganese	.1% P.S.	isolated i.c.* M.D.° .005"	General roughening of surface isolated i.c. M.D. 0.004"	General sub-grain i.c. M.D. .013"
	Un-stressed	negligible attack.	General shallow attack isolated i.c. M.D. .003"	Severe i.c. and general sub-grain i.c. with long. tendency. M.D. .026"
Normal Manganese	.1% P.S.	General pitting & sub-grain i.c. M.D. .001"	General shallow attack isolated i.c. M.D. .004"	Sub-grain i.c. penetrating on tension side. M.D. .013"
	Un-stressed	General shallow pitting sub-grain i.c. M.D. .005"	General shallow attack, isolated i.c. M.D. .004"	Slight general sub-grain i.c. with long. tendency. M.D. .008"

* i.c. = intercrystalline corrosion.

o M.D. = maximum depth.

TABLE 10.

EFFECT OF REMOVAL OF CORROSION PRODUCT
ON CORROSION OF HE 15.

Removal of corrosion product.	2 Months		7 Months	
	Visual	Micro	Visual	Micro
Vertical daily	Uniform attack No foliation.	Slight general foliation, M.D.* .005"	General attack severe isolated foliation.	General pitting and foliation. M.D. .005"
Horizontal daily	Foliation on inside web	" M.D. .005"	General attack. Severe foliation inside channel.	" M.D. .005"
Vertical twice weekly	Possible foliation on inside web.	General foliation to .004" one pit M.D. .008"	General attack, severe foliation inside web.	General foliation. M.D. .005"
Horizontal twice weekly	"	General foliation. M.D. .005"	General attack severe foliation inside channel.	General foliation. M.D. .010"
Vertical weekly.	Uniform attack no foliation.	Slight general foliation. M.D. .005"	General attack. Less severe foliation.	General pitting and foliation. M.D. .007"
Horizontal weekly.	Foliation on inside web and flanges.	" M.D. .005"	General attack. Severe foliation inside channel.	General pitting and foliation. M.D. .005"

*M.D. = Maximum Depth.

TABLE 10 (CONT'D).

Removal of corrosion product.	2 Months		7 Months.	
	Visual	Micro	Visual	Micro
Vertical bi-weekly	Possible foliation on web.	Slight general foliation. M.D.* .007"	General attack, severe foliation on web.	General pitting and foliation. M.D. .006"
Horizontal bi-weekly.	Uniform attack. No foliation.	" M.D. .007"	General attack, severe foliation inside channel.	General pitting and foliation. M.D. .006"
Horizontal no removal.		Slight general foliation. M.D. .004"	General attack with slight foliation.	General pitting and foliation. M.D. .005"
Horizontal no removal.		Slight general foliation .003" locally to .013"	General attack, severe foliation outside web.	General foliation .005". Local foliation .009"

* M.D. = Maximum depth.

TABLE 11.

LOSS IN WEIGHT OF HE 10 AND HE 15 SPECIMENS AFTER 3, 6 and 12 MONTHS' EXPOSURE IN THE SO2 BEAKER TEST WITH VARIOUS ADDITIONS OF HCl.

HE 10				HE 15			
	Loss in Weight				Loss in Weight		
HCl addition.	3 months	6 months	12 months	HCl addition	3 months	6 months	12 months
3 ml	.0448 .0488	.0616 .0423	.209 .189	3 ml	.1764 .6014*	.3474 .3709	.379ø .534ø
6 ml	.0656 .0625	.0490 .0912	.294 .391	6 ml	.2811 .2511	.6022 .6432	.105ø ø
9 ml	.0425 .0307	.0552 .0697	.290 .243	9 ml	.2128 .2469	.4198 .4407	.393ø .715ø

*Specimen dipped into solution.

øUnreliable due to type of attack.

TABLE 12.

TENSILE TESTS ON HE 10 AND HE 15 SPECIMENS AFTER 3, 6 and 12 MONTHS' EXPOSURE IN SO_2 BEAKER TESTS WITH VARIOUS ADDITIONS OF HCl.

	HE 10						HE 15					
HCl addition.	3 months		6 months		12 months		3 months		6 months		12 months	
3 mls	18.7	11	18.6	12	18.2	17	26.8	7	27.8	5	23.0	7
	18.7	12	18.7	13	17.9	15	28.5	6	29.4	9	22.8	7
6 mls	18.4	11	17.9	11	17.1	12	27.2	6	23.4	2	25.8	5
	18.5	14	18.4	15	16.0	10	27.3	7	22.4	3	20.1	4
9 mls	18.6	14	18.7	15	16.9	14	27.8	6			26.4	6
	18.4	14	18.2	11	16.1	12	27.7	6	24.9	3	23.8	4

TABLE 13.

MICROEXAMINATION OF HE.10 AND HE 15. SPECIMENS AFTER 3, 6 and 12 MONTHS' EXPOSURE TO THE SO_2 BEAKER TEST WITH VARIOUS ADDITIONS OF HCl.

HCl Additions.	Microexamination. 3 months	6 months	12 months.
		HE 10.	
3 mls		Slight i.c.* M.D. .002"	Slight general i.c. - rounded pits. M.D. .013"
6 mls	Very slight i.c. and pitting. M.D. .002"	Slight i.c. M.D. .004"	Slight general i.c. some pitting. M.D. .012"
9 mls	Slight i.c. and pitting. M.D. .005"	Slight i.c. and i.c. pitting. M.D. .011"	Slight general i.c. - rounded pits. M.D. .014"
		HE15.	
3 mls	General foliation. M.D. .011"	Slight general foliation. M.D. .011"	General severe foliation. M.D. .030"
6 mls	General foliation. M.D. .021"	General foliation. M.D. .009"	General and severe foliation. M.D. .015"
9 mls	General foliation. M.D. .021"	General foliation. M.D. > .011"	General foliation with rounded pits and isolated severe subgrain attack. M.D. .014"

*i.c. Intercrystalline corrosion.

TABLE 14.

EFFECT OF HEAT TREATMENT ON LOW Mn(A) AND NORMAL Mn(B) RE 15 .1" DISC SPECIMENS. RESULTS OF VISUAL EXAMINATION AFTER 1, 3 and 6 MONTHS' EXPOSURE TO 3% NaCl SPRAY.

Alloy	S.H.T 500°C. Hrs	Ageing 170°C. Hrs.	1 month	3 months	6 months.
A	1	4	General attack. Isolated deep pits.	General attack Isolated deep pits.	Isolated large pits
	1	24	-do-	-do-	Isolated pits
	1	168	-do-	General attack	General attack
	4	4	Isolated pits	General attack. Isolated pits.	Slight General pits
	4	24	Slight General pits.	General attack.	General attack
	4	168	-do-	General attack Isolated pits.	Slight general pits.
	24	4	Isolated pits	General attack isolated pits	-do-
	24	24	Slight General pits.	General attack	General attack
	24	168	General attack Isolated large pits.	General attack	Isolated atack.
B	1	4	Isolated deep pits.	General attack. Isolated pits.	General pits Isolated deep pits.
	1	24	-do-	-do-	-do-
	1	168	Slight pits	-do-	Slight general deep pits.

TABLE 14. CONT'D.

Alloy	S.H.T. 500°C Hrs	Ageing 170°C. Hrs.	1 month	3 months	6 months
B	4	4	Isolated deep pits.	General attack. Isolated pits.	Slight general deep pits.
	4	24	-do-	-do-	-do-
	4	168	-do-	Slight general attack. Isolated pits.	Slight general pits.
	24	4	-do-	-do-	Slight general deep pits.
	24	24	Isolated attack.	-do-	Slight pits.
	24	168	-do-	General attack. isolated pits.	-do-

TABLE 15.

EFFECT OF HEAT TREATMENT ON LOW Mn(A) AND NORMAL Mn(B) HS 15.05" SPECIMENS. RESULTS OF VISUAL EXAMINATION AFTER 1,3 AND 6 MONTHS' EXPOSURE TO 3% NaCl SPRAY.

Alloy	S.H.T 500°C Hrs	Ageing 170°C. Hrs.	1 month	3 months	6 months
A	4	4	Isolated pits.	Isolated severe pits.	Slight general deep pits.
	4	24	Slight general pits.	-do-	-do-
	4	168	-do-	General severe isolated large pits.	-do-
	24	4	Isolated deep pits.	General attack, severe locally.	-do-
	24	24	Isolated pitting.	-do-	General attack.
	24	168	Slight general attack.	General attack. Isolated deep pits.	-do-
B	4	4	Isolated deep pits.	-do-	Isolated severe pits.
	4	24	Slight general attack.	-do-	-do-
	4	168	General attack.	-do-	-do-

TABLE 15 (CONT'D).

Alloy	S.H.T. 500°C. Hrs	Ageing 170°C. Hrs	1 month	3 months	6 months
B	24	4	Slight general attack.	Isolated Large pits.	Isolated severe pits.
	24	24	-do-	Isolated pits	General shallow attack.
	24	168	-do-	General attack. Isolated pits.	-do-

TABLE 16.

EFFECT OF HEAT TREATMENT ON LOW Mn(A) AND NORMAL Mn(B) HS15 .036" SPECIMENS. RESULTS OF VISUAL EXAMINATION AFTER 1,3 AND 6 MONTHS' EXPOSURE TO 3% NaCl SPRAY.

Alloy	S.H.T. 500°C. Hrs	Ageing 170°C. Hrs.	1 month	3 months	6 months
A	4	4	Isolated deep pits.	Isolated pits.	Isolated large pits.
	4	24	Slight general attack.	General attack. Isolated pits.	Slight general large pits.
	4	168	General attack	-do-	-do-
	24	4	Isolated deep pits.	-do-	Specimen disintegrating.
	24	168	General attack.	General attack. Isolated deep pits	General pits
B	4	4	Isolated deep pits.	Isolated severe pits.	General large pits.
	4	24	Slight general attack.	General attack. Isolated severe pits.	-do-
	4	168	General attack.	General attack. Isolated severe pits.	-do-
	24	4	Isolated deep pits.	-do-	-do-
	24	24	Isolated pits	General attack.	General attack.
	24	168	General attack. Isolated deep pits.	-do-	-do-

TABLE 17.

EFFECT OF HEAT TREATMENT ON LOW Mn(A) AND NORMAL Mn(B) HE15 .1" DISC SPECIMENS. RESULTS OF MICRO-EXAMINATION AFTER 1, 3 AND 6 MONTHS' EXPOSURE TO 3% NaCl SPRAY.

Alloy	S.H.T. 500°C. Hrs.	Ageing 170°C. Hrs.	1 month	3 months	6 months
A	1	4	Slight general layer attack. M.D. 037"	General pitting associated with layer attack. M.D. xx	General pitting associated with layer attack, slight i.c.x and subgrain attack. M.D. xx
	1	24	Slight layer attack. M.D. .013"	-do- M.D. .035"	-do- Less layer than above but more subgrain attack. M.D. .024"
	1	168	General i.c. and layer attack. M.D. .016"	-do- less than above. M.D. xx	-do- less layer than above. M.D. .011"
	4	4	General i.c. isolated i.c. Associated with layer attack. M.D. .009"	General pitting associated with layer attack. M.D. xx	Samd as 1.4 above. M.D. xx
	4	24	-do- M.D. .015"	-do- but less than above. M.D. xx	-d - but slightly less pitting. M.D. .040"
	4	168	-do- but less than above. M.D. .010"	-do- M.D. .029"	Isolated pits associated with layer attack. Slight i.c. and subgrain attack. M.D. .026"

TABLE 17. (CONT'D).

Alloy	S.H.T. 500°C. Hrs	Ageing 170°C. Hrs.	1 month	3 months	6 months
A	24	4	Isolated layer attack. M.D. .021"	General layer attack. M.D. **	General layer attack. Slight i.c. and sub-grain attack. M.D. **
	24	24	-do- M.D. .015"	-do- less general than above. M.D. .021"	-do- less general than above. M.D. .022"
	24	168	-do- M.D. .008"	-do- M.D. **	-do- slightly less than above. M.D. .024"
B	1	4	Slight general pitting and layer attack. M.D. .028"	Slight layer attack. M.D. .029"	Slight general pitting associated with layer attack and sub-grain attack. M.D. .032"
	1	24	-do- M.D. .013"	Isolated layer and pitting, one deep large pit. M.D. **	-do- M.D. .026"
	1	168	-do- M.D. .010"	Slight general layer attack. M.D. .026"	-do- M.D. .026"
	4	4	-do- M.D. .040"	Slight general layer attack, some pitting. M.D. **	-do- M.D. .021"
	4	24	-do- but less than above. M.D. .005"	-do- M.D. **	-do- M.D. .021" one large pit. M.D. **

TABLE 17. (CONT'D).

Alloy	S.H.T. 500°C. Hrs.	Ageing 170°C. Hrs.	1 month	3 months	6 months
B	4	168	Isolated pitting and layer attack. M.D. .009"	Slight pitting& layer attack. M.D. .013"	Slight general pitting associated with layer and sub-grain attack. M.D. .024"
	24	4	Slight general attack. M.D. .002" isolated pitting and layer attack. M.D. .012"	General pitting and layer attack. M.D. .016"	-do- but more general than above. M.D. .027"
	24	24	-do- M.D. .003"	Slight pitting and layer attack-some sub-grain attack. M.D. .008"	-do- M.D. .016"
	24	168	-do- but less general than above. M.D. .007"	-do- M.D. .008"	-do- but less general than above. M.D. .021"

* Intercrystalline corrosion.

** Corrosion attack penetrates half way or more through specimen.

TABLE 18.

EFFECT OF HEAT TREATMENT ON LOW Mn(A) AND NORMAL Mn(B) HS 15 .05" SPECIMENS. RESULTS OF MICROEXAMINATION AFTER 1, 3 and 6 MONTHS' EXPOSURE.

Alloy	S.H.T. 500°C. Hrs.	Ageing 170°C. Hrs.	1 month	3 months	6 months
A	4	4	Isolated i.c.* pits. M.D. .008"	Slight i.c. pits M.D. .019"	General i.c.pits **
	4	24	Slight general i.c. M.D. .005"	General i.c. pits. M.D. .013"	-do- **
	4	168	Slight i.c. pits. M.D. .009"	-do- M.D. .017"	-do- M.D. .019"
	24	4	Slight general i.c. M.D. .015"	Slight general i.c. pits. M.D. .022"	-do- **
	24	24	Slight i.c. M.D. .004"	General pits to .004". Isolated i.c. M.D. .011"	-do- M.D. .020"
	24	168	Very slight i.c. M.D. .003"	Slight i.c. M.D. .009"	-do- M.D. .011"
B	4	4	Very slight i.c. pits, slight longitudinal tendency. M.D. .004"	General i.c. Slight longitudinal tendency. M.D. .024"	Slight general i.c. slight longitudinal tendency M.D. .016"
	4	24	Slight general i.c. pits. Slight longitudinal tendency. M.D. .009"	-do- M.D. .022"	-do- M.D. .016"

TABLE 18.(CONT'D).

Alloy	S.H.T. 500°C. Hrs.	Ageing 170°C. Hrs.	1 month	3 months	6 months
B	4	168	Very slight i.c.	General i.c. Slight longitudinal tendency. M.D. .010"	Slight general i.c. slight longitudinal tendency. M.D. .013"
	24	4	Very slight i.c. Slight longitudinal tendency. M.D. .005"	Isolated i.c. M.D. .034"	General i.c. M.D. .021"
	24	24	Very slight i.c.	General i.c. Slight longitudinal tendency. M.D. .006"	Slight i.c. Slight longitudinal tendency. M.D. .005"
	24	168	General i.c. Slight longitudinal tendency. M.D. .003"	-do- M.D. .005"	-do- M.D. .010

* Intercrystalline corrosion.
** Corrosion attack penetrates half way or more through specimen.

TABLE 19.

EFFECT OF HEAT TREATMENT ON LOW Mn(A) AND NORMAL Mn(B) HS15 .036" SPECIMENS. RESULTS OF MICROEXAMINATION AFTER 1, 3 AND 6 MONTHS' EXPOSURE.

Alloy	S.H.T. 500°C. Hrs.	Ageing 170°C. Hrs.	1 month	3 months	6 months.
A	4	4	Negligible attack.	Isolated i.c.* M.D.**	Severe i.c. pits, specimen almost disintegrated.
	4	24	General i.c. pits. M.D. .005"	General i.c. pits. M.D. .016"	-do-
	4	168	Slight pits. M.D. .010"	-do- M.D. .016"	-do-
	24	4	Isolated i.c. M.D. .016"	Isolated i.c. **	-do-
	24	168	Slight general i.c. M.D. .005"	General i.c. M.D. .012"	General i.c. pits. M.D. .011"
B	4	4	Slight general i.c. M.D. .010"	Slight general i.c. pits. M.D. .022"	General i.c. **
	4	24	General i.c. M.D. .013"	Slight general i.c. M.D. .022"	Slight general i.c. M.D. .019"
	4	168	Slight i.c. M.D. .005"	-do- M.D. .016"	Isolated i.c. specimen disintegrating.

TABLE 19. (CONT'D).

Alloy	S.H.T. 500°C. Hrs.	Ageing 170°C. Hrs.	1 month	3 months	6 months.
B	24	4	General i.c. M.D. .016"	General i.c. pits. **	General i.c. pits. **
	24	24	Negligible attack.	Slight general pits. M.D. .004"	General i.c. pits, longitudinal tendency. M.D. .008"
	24	168	Isolated i.c. M.D. .005"	General i.c. pits. M.D. .006"	-do- M.D. .008"

* Intercrystalline corrosion.

** Maximum Depth half way through specimen or more.

TABLE 20.

STRESS CORROSION TESTS IN DIRECT TENSION ON H15 SHEET AND EXTRUDED (STRESSED TRANSVERSE TO EXTRUSION DIRECTION) SPECIMENS.

Material			Stressed and Corroded		Unstressed Corroded specimens.	
	UTS tons/in^2	Elong. %	Stress tons/in^2	Time to failure days.	U.T.S. tons/in^2	Elong. %
Sheet Controls			24	2	28.2	5
			24	3	28.1	6
			20	3	28.4	8
			20	2-7	25.8	4
	30.1	10	16	3-5	28.9	12.5
	30.4	8	16	13	27.8	8
			12	10		
			11	Started		
			10	132	Started.	
			10	96		
			8	206		
			8	96		
			6	Started		
Extrusion Controls			24	4	27.8	3
			24	3	28.1	3.5
			20	4	26.5	3
			20	5	27.0	3
			16	7	27.7	3
	28.2	4	16	7	26.4	2
	28.4	4	10	3-6		
			8	9		
			7	Started		
			6	108	Started.	
			6	Started		
			4	Started		

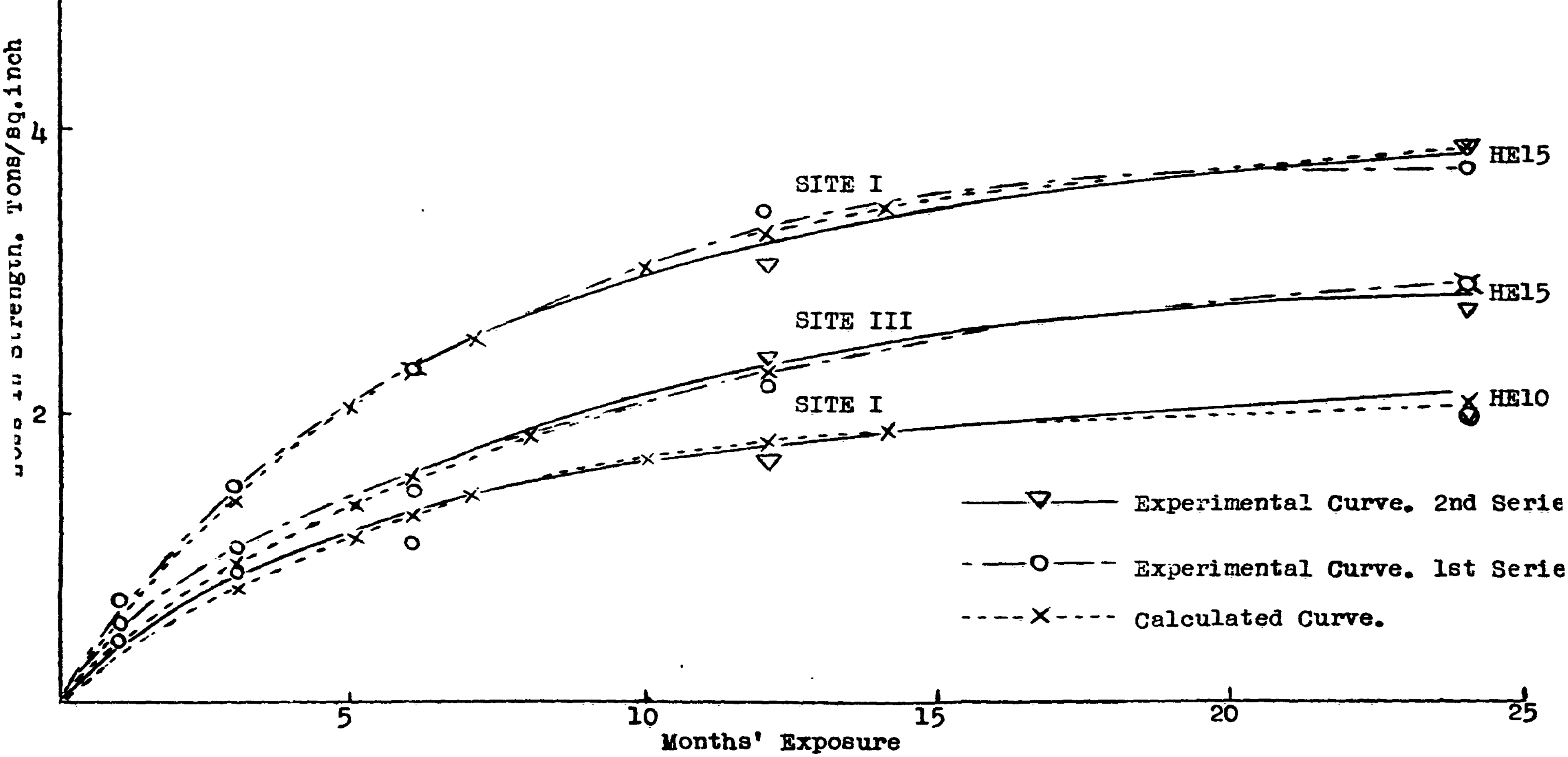
TABLE 21.

STRESS CORROSION TESTS ON COATED SHEET SPECIMENS STRESSED IN CANTILEVER TYPE OF JIG.

Type and Thickness of Coating.	Stress tons/sq.in.	Days to failure.
Sprayed commercial purity aluminium (99.7%) .002" (nominal)	24	$>$265 not broken
	18	$>$476 " "
Sprayed Aluminium/1% zinc. .002" (nominal)	24	$>$265 not broken
	18	$>$476 " "
Sprayed Zinc. .002" (nominal)	24	265
	18	$>$354 not broken
	18	129
	15	132
	15	$>$290 not broken
Metallic zinc paint - two brush coats.	24	131
	18	71
	18	41
	15	108
	15	61
Controls shot blasted surface.	24	4
	24	11
	18	14
	15	34

LOSS IN STRENGTH V EXPOSURE PERIOD

FIGURE 1



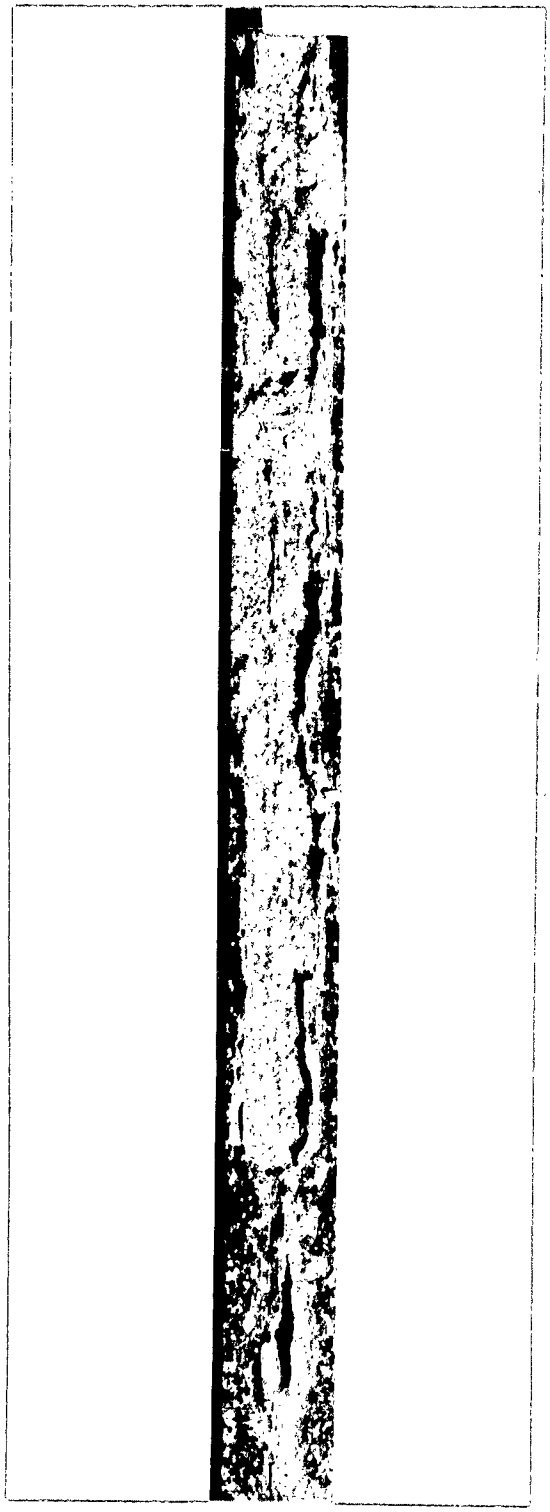


FIGURE 2.

Layer exfoliation from specimen of HE15WP after two years' exposure at Sheffield.

APPENDIX I.

PREPARATION OF SPECIAL BILLETS OF NORMAL AND LOW MANGANESE CONTENT.

Cast billets were made in two alloys of almost identical chemical compositions apart from manganese content. The full chemical compositions were as follows:-

	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti
Low Manganese	4.08	0.54	0.87	0.32	0.08	0.03	0.02	0.02	0.02	$<.02$
Normal Manganese	4.00	0.53	0.93	0.32	0.76	$<.02$	0.03	0.02	0.03	<0.02

The billets were approximately $6\frac{1}{2}$" diameter, x 12" long. One billet in each alloy was cut in half, one half being rolled into sheet and the other half being extruded to 2" diameter bar. The half billets that were rolled to sheet were first of all skimmed to 6" diameter x 6" long, forged to $2\frac{1}{2}$ - 2.5/8" thick, 5-6" wide with the major axis parallel to that of the original billet. At the start of the forging the temperature of the billets was 430°C., and at the finish, 380-395°C. The original bars were upset to approximately 3" in height without spreading. They were cubed and then drawn out on the original axis. The slabs were then rolled to sheet. Hot rolling was carried out at 480°C. in four stages with approximately 40% reduction in thickness at each stage down to the thickness required, i.e., 2", .1", .05" and .036" thick. After rolling, all the strips were annealed at 360°C. for one hour and were then cooled slowly in the furnace over-night. Samples from these sheets were stored in this condition and were solution heat treated at 505 ± 5°C., quenched in cold water and aged for 8 hours at 170 - 175°C.

There was some variation in properties of the material in different forms, but the average properties obtained on test pieces of the same form as those used for corrosion testing were as follows:-

Average mechanical properties.

		U.T.S. tons/in^2	Elong. %
2" Extruded bar (substandard test pieces)			
Low manganese.	Longitudinal.	25.1	12
	Transverse.	26.1	4
Normal manganese.	Longitudinal.	32.8	9
	Transverse.	28.3	4
0.2" sheet.			
Low manganese.	Longitudinal.	27.8	10
	Transverse.	27.2	11
Normal manganese.	Longitudinal.	29.4	9
	Transverse.	29.4	8
0.1" sheet.			
Low manganese.		28.7	10
Normal manganese.		30.2	9
0.05" sheet.			
Low manganese.		28.3	12
Normal manganese.		30.0	10
.1" sheet rolled from 2" extruded bar.			
Low manganese.		29.9	12
Normal manganese.		32.5	11

APPENDIX II.

COMPOSITION OF MELTS OF HE.10 CONTAINING VARIOUS AMOUNTS OF COPPER.

Melt No.	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti
GG 172	≪.01	0.72	1.05	0.31	<.02	<.02	<.02	<.02	<.02	<.02
GG 176	0.022	0.72	1.06	0.34	<.02	<.02	<.02	<.02	<.02	<.02
AG 92(B)	0.030	0.67	0.97	0.31	c.04	<.02	c.02	<.02	<.02	<.02
GG 185	0.088	0.68	1.03	0.31	0.03	<.02	<.02	<.02	<.02	<.02
AG 92(E)	0.160	0.62	0.96	0.31	c.04	<.02	c.02	<.02	<.02	<.02
(G)	0.21	0.66	0.95	0.31	c.04	<.02	c.02	<.02	<.02	<.02
(H)	0.32	0.65	0.95	0.31	c.04	<.02	c.02	<.02	<.02	<.02
(J)	0.47	0.60	0.95	0.31	c.03	<.02	c.02	<.02	<.02	<.02

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